

HEALTH MONITORING AND MANAGEMENT

Introduction

Rocky Mountain bighorn sheep, *Ovis canadensis canadensis*, are susceptible to many diseases and parasites. While most diseases and parasites do not cause severe morbidity or mortality by themselves, in combination they can result in reduced reproductive potential and death. Much research has been conducted regarding disease issues in bighorn sheep, particularly respiratory disease, or pneumonia. The decline of bighorn sheep in the late 1800s is thought to have occurred largely because of the introduction of domestic sheep (Buechner 1960). Domestic sheep are host to pathogens for which bighorn sheep have little or no immunity. Transmission of disease agents from domestic animals to bighorn sheep is not entirely understood; however, it is widely recognized by those who deal with animal health (wild and domestic) that when domestic sheep and wild sheep intermingle, wild sheep can die in significant numbers (Martin et al. 1996).

In January 2007, the Western Association of Fish and Wildlife Agencies (WAFWA), comprised of 23 state and provincial wildlife agencies from the western United States and western Canada, established a Wild Sheep Working Group (WSWG). The WSWG was charged with developing a comprehensive, west-wide assessment of all facets of wild sheep management, from the desert Southwest to the far north. The first task undertaken by the WSWG was to develop a framework of recommendations for state, federal, and provincial agencies to use when developing management guidelines for dealing with potential contact or interaction between wild sheep and domestic sheep and goats. Recognizing the diversity and complexity of applying such guidelines across the wide variety of habitats and jurisdictions represented within WAFWA was critical. The members of this initial WSWG were specifically selected based on their familiarity with and knowledge of this issue and represented a diverse mix of wildlife veterinarians, wild sheep managers, and agency wildlife program leaders from the United States and Canada. While not official members of WAFWA, the U.S. Forest Service (USFS) and the Bureau of Land Management (BLM), because of the role these agencies have in managing wildlife habitats, became adhoc members on the WSWG.



Through an exhaustive literature review, an extensive body of scientific literature on the effects of disease on bighorn populations was accumulated. The literature includes: 1) numerous examples of bighorn die-offs due to disease, 2) documentation of bighorn die-offs occurring as early as the mid-1800s and in every state in the western United States, 3) information linking bighorn die-offs to known or suspected contact with domestic sheep, 4) experimental studies where clinically healthy bighorn sheep have developed pneumonia and died within days to weeks following contact with clinically healthy domestic sheep, 5) identification of a variety of diseases and pathogens implicated in die-offs, particularly bacterial pneumonia (Pasteurellosis)

caused by *Mannheimia haemolytica* (formerly *Pasteurella haemolytica*) or other species of closely related *Pasteurella* bacteria, 6) a wealth of information suggesting consensus among wildlife biologists and veterinarians experienced in bighorn sheep management that domestic sheep and goats and bighorn sheep must be kept separated in order to maintain healthy bighorn populations (Foreyt and Jessup 1982; Goodson 1982; Onderka and Wishart 1988; Foreyt 1989; Desert Bighorn Council Technical Staff 1990; Callan et al. 1991; Cassirer et al. 1996; Martin et al. 1996; USDI Bureau of Land Management 1998; Bunch et al. 1999; Singer et al. 2000a, 2000b, 2000c, 2000d; Monello et al. 2001; Singer et al. 2001; Dubay et al. 2002; Garde et al. 2005).

The WSWG concluded that there is a preponderance of evidence that indicates significant risk exists for disease transmission from domestic sheep and goats to wild sheep. In some cases where contact occurred, consequences to wild sheep have endangered entire populations. Consequently, the WSWG recommended that wild sheep managers take appropriate steps to minimize, mitigate, or eliminate the opportunities for disease transmission through commingling of wild sheep with domestic sheep and goats.

The report and subsequent recommendations produced by the WSWG titled "Recommendations for Domestic Sheep and Goat Management in Wild Sheep Habitat", was transmitted to WAFWA directors on June 21, 2007, and was unanimously endorsed by the directors on July 12, 2007. This report can be accessed currently at the WAFWA website (<http://www.wafwa.org/html/wswg.shtml>). The president of WAFWA, Jeffery R. Vonk, forwarded the report to federal land management agencies on August 31, 2007, recommending that the report and the recommendations included therein be used as the basis for creation or revision of policy-level direction in the federal agencies. This report is the basis for much of the content and many of the recommendations made in this section.

Extensive research has been conducted in an effort to understand the mechanisms involved in disease transmission from domestic animals to bighorn sheep. A number of penned experiments have been conducted where domestic sheep were placed in contact with bighorn sheep (Foreyt 1989, 1990, 1994; Onderka and Wishart 1988). In most experiments all bighorn sheep subsequently died of respiratory disease (pneumonia). Other experiments included mixing bighorn sheep with elk, white-tailed deer, and mule deer; elk alone; domestic goats; mountain goats; llamas; cattle; horses; and steers (Foreyt 1992a, 1994; Foreyt and

Lagerquist 1996). In these experiments only two of 39 bighorn sheep died. Other research included the inoculation of *Mannheimia haemolytica* cultures, which is the strain of bacteria most often implicated in pneumonia in bighorn sheep, from domestic sheep into bighorn sheep (Foreyt et al. 1994; Foreyt and Silflow 1996; Onderka et al. 1988). Of the 13 bighorn sheep inoculated with these bacteria, 12 died of acute bronchopneumonia.

Other strains of bacteria, specifically *Pasteurella multocida* and *Bibersteinia trehalsoi*, have been identified as the pathogenic agent in other bighorn sheep die-offs. Coburn (2005) provides a good contemporary discussion of diseases in bighorn sheep and how stress may contribute in outbreaks of disease in bighorn populations.

While the exact mechanism for the transmission and subsequent manifestation of pathogenic agents from domestic sheep to bighorn sheep isn't known, research is currently being conducted that implicates another bacteria, *Mycoplasma ovipneumoniae*, as potentially having a role in disease transmission between the species.

Bighorn sheep populations in Montana are generally robust and reproductive. However, disease-related issues have affected lamb recruitment and population vitality. Reduced lamb production and recruitment for two or more years is a common complication following pneumonia die-offs (Onderka and Wishart 1984; Coggins and Mathews 1992; Ryder et al. 1994; Aune et al. 1998).

Occasionally, large-scale die-offs have occurred, essentially reducing populations to a few individuals (Aune et al. 1998; Semmen 1996; Coggins and Mathews 1992; Onderka and Wishart 1984). Major population declines due to epizootic events are still a periodic challenge to maintaining bighorn sheep populations. Since 1984, there have been significant die-offs in 14 bighorn populations in Montana.

The preponderance of information on bighorn sheep disease issues suggests that contact between domestic sheep and goats and bighorn sheep should be avoided and that major disease events are more likely to occur in bighorn sheep herds where contact with domestics has occurred. In response to this information, FWP has tried to establish a buffer zone of up to nine miles between domestic sheep and goats and bighorn sheep populations (USDI 1998). This strategy has not successfully eliminated contact between the species, and mortality events have still occurred. However, there are bighorn sheep herds in areas where potential contact with domestic sheep or goats

could occur that have not suffered major die-offs. The association of bighorns and domestic sheep and goats does not result in disease with every contact, but continued or even periodic contact likely increases the risk that a major disease event will eventually occur. In general, maintaining separation of wild and domestic animals is considered an important aspect in reducing the potential for disease transmission between domestic herds and wildlife populations.

Although Montana generally attempts to lethally remove bighorn sheep known to have had contact with domestic sheep and goats, only one of seven administrative regions has such a written protocol. The intent of this removal is to reduce the potential of pathogen transfer from domestics to bighorns. Sick bighorns are generally removed from populations for disease testing purposes and to reduce the likelihood of pathogen transmission from the sick individual(s) to the remaining herd. Attempts have been made to treat animals during and after die-offs to increase survival. While there has been limited success with field treatment of bighorns during pneumonia outbreaks through application of antibiotics, treatment is often difficult to accomplish (Coggins and Matthews 1998). Administration of an adequate dosage of antibiotics to large numbers of free-ranging animals is extremely difficult and expensive. Additionally, treatment of bighorns through application of anthelmintics or vaccines after the die-off event, with the objective of improving lamb survival, has generally not been effective (Aune et al. 1998; Miller et al. 2000; Cassirer et al. 2001). Treatment attempts that result in partial or incomplete control of targeted pathogens could result in resistant strains. Prophylactic treatment should only be attempted after careful consideration of the likelihood of success and all of the consequences of the program, both intended and unintended.

Herd health monitoring efforts have historically been limited to opportunistic tissue and sample collections during bighorn sheep capture events, and tissue collection when sick animals are removed from populations or when bighorns coming in contact with domestic livestock have been killed. Additional health monitoring has occurred through occasional collections of fecal samples in attempts to determine parasite loads. Although these monitoring efforts have supplied important information on the presence of pathogens and overall population health, currently there is no systematic health-monitoring or disease management program in place for Montana bighorn sheep populations.

There are many challenges in assessing and managing the health of bighorn sheep. This section of the Conservation Strategy provides a description of some of the major diseases and parasites that FWP tests for and that potentially compromise bighorn sheep health. In the next section, the proposed “Bighorn Sheep Herd Health Program” is outlined which will provide direction for monitoring the health of our bighorn sheep herds but remain flexible enough to incorporate new methods and technologies as they are developed. As part of FWP’s overall bighorn sheep health management and to provide consistency across the state, we have developed a statewide written protocol for resolving situations where bighorn sheep and domestic sheep and goats commingle. One of the major issues surfacing in relation to bighorn sheep health is the use of domestic sheep and goats for noxious weed control in the vicinity of bighorn sheep. FWP has developed recommendations to land managing agencies and others using this management technique. In spite of the best efforts to promote bighorn sheep health, now and in the future, history indicates that catastrophic die-offs will likely occur again sometime in the future. As part of FWP’s bighorn sheep health program, a protocol has been developed outlining how to respond to these events.

Diseases and Parasites of Rocky Mountain Bighorn Sheep

Montana FWP routinely collects health status data during bighorn sheep translocation efforts and in the advent of a die-off (Appendix F). This disease and parasite data falls into three categories: bacterial diseases, viral diseases and parasites (protozoa and nematodes). The particular diseases and parasites tested for and a brief description of their significance as a health threat to bighorn sheep follows. Many diseases that bighorn sheep are susceptible to have their origin in domestic livestock. The effect on bighorn sheep for many of these diseases is not fully documented and is inferred from studies done on domestic animals.

During the latter stages of producing this conservation strategy WAFWA and their associated Wildlife Health Committee (WHC) produced a report titled “Wild Sheep Herd Health Monitoring Recommendations”. These recommendations can be accessed currently at the WAFWA web site (<http://www.wafwa.org/html/wswg.shtml>). The WHC recommendations reflect much that is contained in this Health Monitoring and Management section and is complimentary to the content herein. FWP

currently utilizes recommendations produced by the WHC such as in the proper collection of bacterial samples from bighorn sheep.

Bacterial Diseases

- 1) *Brucella abortus* – *Brucella abortus* is found primarily in cattle, elk, and bison and can cause abortion, birth of nonviable offspring, and infertility (Thorne et al. 1982). Tests for the presence of *B. abortus* in bighorn sheep in Montana have been negative. In a small group of bighorns confined adjacent to a group of confined elk in Wyoming, Kreeger et al. (2004) reported contraction of *B. abortus* by bighorn sheep from contact with an aborted elk fetus. Brucellosis is a zoonotic disease.
- 2) *Brucella ovis* – *Brucella ovis* occurs in domestic sheep and wild sheep. Bighorn sheep in Idaho and California have tested positive for *B. ovis* (Dubay et al. 2002). The significance of *B. ovis* to bighorn sheep is not known at this time.
- 3) Anaplasmosis – Anaplasmosis is a vector (tick, biting flies) rickettsial infection-causing anemia in cattle and wildlife (Thorne et al. 1982). Anaplasmosis can be severe in cattle but produces only a mild disease in wildlife. Wildlife may be a minor carrier of the disease.
- 4) Leptospirosis – Eight species of Leptospirosis are tested for in Montana. Leptospirosis is a contagious disease with clinical signs including fever, jaundice, loss of appetite, abnormally colored urine, and abortion. Animals usually recover from the disease but can carry and shed bacteria after clinical signs cease. Leptospirosis is a widespread zoonotic disease with uncertain status for bighorn sheep but seems to pose a minor health risk (Dubay et al. 2002).
- 5) *Haemophilus somnus* – Organisms of this genus are normal and sometimes pathogenic inhabitants of the upper respiratory tract of humans and animals. *Haemophilus ovis* has been associated with one outbreak of bronchopneumonia in domestic sheep (Thorne et al. 1982).
- 6) Infectious Keratoconjunctivitis (IKC) – IKC is not routinely tested for but has been a serious disease of bighorn sheep in Montana and other parts of the West. This disease is characterized by ocular irritation, corneal opacity, ulceration, and blindness. *Chlamydia* spp., *Mycoplasma* spp., *Branhamella* spp., and *Moraxella* spp. have been implicated as the causative agents of this disease in bighorn sheep. An outbreak of IKC in Yellowstone National Park in 1981 resulted in mortality of approximately 60% of 500 bighorns (Meagher 1982). It was also detected in the Bitterroot in 1991. Bighorn sheep in the Silver Bell Mountains in Arizona contracted IKC and Contagious Ecthyma from domestic goats in 2003 (Jansen et al. 2007). Thirty-nine percent of the population during the epizootic went blind with 50% of those recovering sight and 50% dying. Those that regained eyesight were blind for an average of 44 days. Primary cause of death in affected animals was predation (lions) and secondarily, starvation.
- 7) Bacteria of the genus *Mannheimia*, *Pasturella*, *Bibersteinia* and *Mycoplasma* are tested for according to the WAFWA/WHC protocols during trapping of bighorns for transplant or during a die-off event. Some species of these bacteria are endemic to bighorn sheep and occur as normal bacterial flora of the upper respiratory tract (Thorne et al. 1982). Different species of the above genera are typically implicated and identified during pneumonia outbreaks in bighorn sheep. The exact mechanisms manifesting virulence in these bacteria is not fully understood at this time.

Viral Diseases

- 1) Blue Tongue (BTV) and Epizootic Hemorrhagic Disease (EHD) – These two closely related diseases can impact many free-ranging and domestic ungulates. Viruses are transmitted by biting midges, and affected animals can die acutely or demonstrate increased respiration rates, weakness, diarrhea, and hemorrhages in most organs (Thorne et al. 1982). In Montana these viruses occur mostly in the central and eastern portions of the state and have caused major die-off events, primarily among deer.
- 2) Infectious Bovine Rhinotracheitis (IBR) – IBR belongs to the herpes virus group and causes respiratory disease in cattle. IBR is widespread but has not been implicated in bighorn sheep epizootics and appears to pose little risk to bighorn sheep (Dubay et al. 2002).
- 3) Bovine Viral Diarrhea (BVD) – BVD is a common disease in cattle with

clinical signs including fever, depression, alimentary tract erosions, dehydration, diarrhea, weak neonates and abortion (Dubay et al. 2002). Sero-prevalence for BVD was found in four of nine bighorn sheep populations tested in Montana during the period 1990-1997 and in two of four populations during epizootics during the same time period (Aune et al. 1998). The significance of the presence of BVD in bighorn sheep epizootic events is unknown at this time (Dubay et al. 2002).

- 4) Para Influenza 3 (PI3) – PI3 is common to domestic sheep and cattle but considered to be of low pathogenicity. Sero-prevalence in Montana bighorn sheep is common and has been isolated in pneumonic cases. However, it is not known if the virus served as a primary pathogen or occurred secondarily to other pathogens. PI3 infection alone is considered a minor disease of free-ranging wildlife (Dubay et al. 2002).
- 5) Bovine Respiratory Syncytial Virus (BRSV) – BRSV is a respiratory virus that has occasionally been associated with pneumonia complex in bighorn sheep. Whether the virus served as a primary pathogen in pneumonia or as a secondary infection is not known. The detection of BRSV in serologic surveys does not signal impending problems, but BRSV should be monitored and considered suspect should changes in herd health be observed. Six of nine herds tested in Montana showed serologic prevalence for BRSV (Aune et al. 1998).
- 6) Contagious Ecthyma (CE) – Also known as soremouth or orf, CE is caused by a parapoxvirus and results in painful lesions and scabs around the mouth, face, and teats of ewes (Jessup 1985). While CE is not routinely tested for in Montana, it was detected in the Missouri River Breaks in 1998 and 2003, Sun River in 2002, and the Bitterroot in 2002. The CE virus may remain viable in scabs or soil for up to 22 years (Jessup and Boyce 1993). CE is transmissible to humans, and care needs to be exercised when handling affected animals. Lambs may be more seriously affected as sores on the muzzle make nursing painful (Dubay et al. 2002), or affected ewes may reject suckling lambs because of painful teats (Jessup and Boyce 1993). Malnutrition of the lamb results in either case.

- 7) Ovine Progressive Pneumonia (OPP) – OPP is caused by a slow-growing retrovirus and can be highly fatal to domestic sheep. Extensive testing of free-ranging bighorn sheep throughout the western United States has not detected antibodies for OPP (Jessup and Boyce 1993).

Ectoparasites

- 1) Scabies – Scabies is caused by a parasitic mite (*Psoroptes* spp.) infection of the skin, especially of the ears, head, and neck, and was a major cause of bighorn sheep decline throughout their range, including Montana, in the latter half of the 19th century (Couey 1950; Buechner 1960). Severely infected animals may have significantly impaired hearing, making them vulnerable to predation. While Scabies is still a bighorn sheep health issue in parts of the West, it is rare in Montana, with the only recent occurrence in 1999 at the East Fork of the Bitterroot River.

Internal Parasites

Typical monitoring of internal parasites in the past has consisted of analysis of fecal samples collected during translocation of bighorn sheep. Samples are analyzed to determine relative levels of larvae and protozoa and particular species of both parasites in the feces. In addition, three studies were conducted in Montana that analyzed fecal samples along with total worm counts in internal organs (Worley and Seesee 1992; Hoar et al. 1996; Aune et al. 1998; Enk 1999). Worley and Seesee (1992) investigated by postmortem examination 68 bighorn sheep from 11 different populations over an 18-year period. A total of 10 species of nematodes, two species of cestodes (tapeworms), and four species of coccidian (protozoa) were identified. The other two studies looked for the above-mentioned parasites plus the presence and abundance of lungworms, identifying two species. All three studies found a similar number of nematode, cestode, and coccidian species.

Lungworm has often been implicated as a contributing factor in epizootic pneumonic events. However, Aune et al. (1998) looked at *Protostrongylus* spp. larval counts in four bighorn sheep populations that suffered die-offs, finding that counts varied from high to low and one population had no lungworms. Festa-Bianchet (1988), in analyzing a pneumonia epizootic in Alberta, concluded that monitoring fecal counts of lungworm larvae was not a reliable way to predict pneumonia epizootics.

The two most common species of gastrointestinal parasites found in bighorn sheep in Montana in the three previously mentioned studies were *Marshallagia marshalli* and *Nematodirus* spp. *M. marshalli* is found in the abomasums (fourth stomach) and causes damage to the mucosa of the stomach, decreasing the assimilation of nutrients, and results in the loss of appetite and slow weight gain (Thorne et al. 1982). *Nematodirus* spp. occurs in the small intestine. Worms penetrate the intestinal mucosa causing considerable destruction that results in a decrease in the absorption of nutrients and other complications (Thorne et al. 1982). When found in large numbers in domestic sheep, *Nematodirus* spp. infestations result in diarrhea, weakness, and weight loss.

Worley and Seesee (1992) identified four species of coccidian in three different bighorn sheep populations in Montana. All species were in the genus *Eimeria* with *Eimeria crandallii* being the predominant species. Aune et al. (1998) identified six species of *Eimeria* in the Upper Rock Creek herd. Clinical signs of *Eimeria* infection include diarrhea, electrolyte imbalances, and damage to the intestinal lining (Worley and Seesee 1992). Severely ill domestic sheep generally have concurrent respiratory or other infections in conjunction with *Eimeria* infection (Thorne et al. 1982).

Proposed Bighorn Sheep Herd Health Program

The proposed Bighorn Sheep Herd Health Program is designed to provide general guidance on monitoring and mitigation of health-related risks posed to bighorn sheep populations in Montana. The program must remain adaptive and allow wildlife managers and wildlife health experts within FWP to adjust strategies as needed on a case-by-case basis or as new information or protocols dealing with bighorn sheep health become available. Ultimately, the goal of the program is to provide direction for the management of bighorn sheep populations and to reduce the risk that catastrophic disease events pose to bighorn populations. An objective is to develop risk assessments to guide incorporation of health monitoring and management strategies into management of bighorn populations along with relevant ecological information, habitat conditions, and management goals. The program consists of three components: monitoring, health risk assessment, and management recommendations. The FWP wildlife veterinarian will direct tissue

collection and testing protocols and provide guidance and training on health assessment techniques. Area wildlife biologists, in conjunction with the wildlife veterinarians will compile data related to herd health and assess the likelihood or “risk” of a major disease event. Management recommendations aimed at reducing the perceived risk will be developed and provided to the regional wildlife manager to include in routine bighorn sheep management and monitoring programs.

Monitoring

Monitoring efforts should combine routine health evaluations, usually achieved through the testing of blood and tissues for select pathogens; routine evaluation of general body condition based on observations of live animals; population composition information including density estimates, sex ratios, and age structure achieved through surveillance activities; habitat condition evaluations; and the continual monitoring of domestic sheep and goat proximity to bighorn populations.

Health evaluation protocols will follow guidelines developed and recommended by the Western Association of Fish and Wildlife Agencies (WAFWA (2007)) <http://www.wafwa.org/5.18.html>, while allowing for alterations based on financial funding, testing requirements deemed necessary by FWP wildlife health officials, or other potential activities deemed relevant for evaluating herd health. The WAFWA guidelines were developed by experts in the wildlife health field and incorporate testing protocols designed to detect and assess known pathogens and provide additional information in areas where data is lacking. Collection of tissues for the purposes of conducting health evaluations should, when possible, occur through the use of hunter-harvested animals or animal capture operations associated with existing research projects or proposed bighorn transplant operations. When necessary, capture of animals for the purposes of herd health evaluations may be required but will be evaluated on a case-by-case basis. In populations not used as a source of animals for transplant stock (and therefore not handled on a regular basis), it is recommended that noninvasive techniques be used to assess the health of these populations (see Genetics section). Routine evaluations of body condition should be conducted in a systematic manner by trained individuals, based on parameters established by the wildlife veterinarian. McCutchen (1985) provided a useful method for visually assessing the physical condition of

bighorn sheep. Data about populations such as density estimates, age structure, sex ratios, and lamb recruitment will be conducted as described in the Population Management and Monitoring section of this document. Results of these observations will be made available to the wildlife veterinarian. Habitat evaluations will be conducted as described in the Habitat Monitoring and Management section of this document and also provided to the wildlife veterinarian. The location of domestic sheep and goat herds within the perceivable range of bighorn sheep populations will be mapped and the potential for interspecies contact evaluated. Other additional information deemed important to evaluating the disease risk of a bighorn population will be incorporated into the risk assessment.

Risk Assessment

Risk assessments will be conducted for each bighorn sheep population in Montana based on the above information. Risk assessment will fall on a continuum from low to high based on data obtained through monitoring efforts. In general, bighorn sheep populations in close proximity or with high likelihood of contact with domestic sheep and/or goats will be considered to be at high risk of experiencing a major disease event. Combinations of other parameters such as the presence of highly pathogenic organisms, high densities, poor habitat conditions, reduced lamb production/recruitment, and the presence of stressors that could contribute to potential catastrophic disease events would also result in a designation of “high risk.” Bighorn sheep herds believed to be at low risk would have population densities considered suitable for existing habitat conditions, demonstrate adequate lamb production/recruitment, maintain suitable sex ratios, and have low levels of potential pathogens. Populations where adequate information is not available to make an accurate assessment of risk would be considered high risk until information becomes available to lower that assessment. The parameters considered for risk assessment will be based on the best available knowledge, and are subject to change as additional information on elements affecting bighorn sheep health becomes available.

Risk Mitigation

In areas where bighorn sheep and domestic sheep or goats share range or contact is possible, formal agreements between FWP and the producer/owner will be drafted outlining response plans should contact occur (see proposed commingling protocol, next section).

Bighorn sheep coming in contact with domestic sheep and goats should be lethally removed immediately either by producers authorized to shoot the animal or by FWP employees who are able to respond to the event in a timely manner. Tissue collections and testing procedures should follow protocols determined by the wildlife veterinarian and/or the wildlife lab supervisor. Additional language should include but not be limited to agreements on timing of range use by domestic sheep and goats, protocols for capture or dispatch of domestic sheep and goats that stray from established herds, and criteria for consideration in developing domestic sheep and goat herd health plans. The goal of these agreements is to allow for the successful management of healthy domestic herds and bighorn sheep populations where ranges overlap or interspecies contact may occur.

Formal agreements should also be drafted with land management agencies regarding domestic sheep allotments, sheep used for weed programs, and habitat management programs and other activities that could impact bighorn sheep populations and herd health. Agreements should delineate agency responsibility and authority. The goal of these agreements should be to propagate responsible stewardship of bighorn sheep habitats and populations while maintaining agency directives.

Management Recommendations

Management recommendations aimed at reducing the overall health risks for bighorn sheep populations will be developed cooperatively with the area biologist and wildlife veterinarian. Recommendations will be made based on risk factors determined through the monitoring activities and population parameters discussed above, the presence of livestock, and the potential for contact and existing mitigation efforts to reduce domestic/bighorn contacts. Recommendations will be presented to the regional wildlife manager for consideration and discussion. The wildlife veterinarian should serve in a consulting role for management decisions with the potential to affect herd health, before implementation of a management action.

Statewide Protocol for Resolving Situations Where Bighorn Sheep and Domestic Sheep and Goats Commingle

Background

Scientific observation and field studies demonstrate that “contact” between domestic

sheep and goats and bighorn sheep is possible under range conditions. Dispersal, migratory, and exploratory behaviors of individual bighorn sheep and the gregarious nature of both wild and domestic sheep may exacerbate the potential, particularly during the rut, for disease introductions and transmission between the species. These behaviors increase risk of contact and subsequent respiratory disease in bighorn sheep, resulting in mortality and reduced future recruitment. The complete range of mechanisms and causal agents that lead to epizootic disease events in bighorns are not thoroughly understood at this point. Regardless, sufficient evidence exists to conclude that it is prudent to prevent contact between these species.

While not all bighorn sheep epizootic disease events can be attributed to contact with domestic sheep and goats, it is generally accepted by wildlife biologists and veterinarians that when bighorn sheep commingle with domestic sheep or goats, bighorn sheep are at an increased risk of a mortality event.

Contact between bighorn sheep and domestic sheep and goats may occur in a variety of situations including but not limited to: 1) grazing allotments and pastures either on private or public lands, 2) trailing through areas where bighorn sheep may occur, 3) hobby farms, and 4) areas where domestic sheep or goats are being grazed for noxious weed control. In any setting, the required course of action following confirmed or suspected contact is the lethal removal of the bighorn sheep. It is the responsibility of each FWP region, where bighorn sheep occur to make the details of this protocol known to producers, managing agencies, and the public at large. In the case of large producers on public or private lands in areas where contact is likely to occur, a written and signed agreement outlining their rights and responsibilities under the terms of this protocol shall be made available to them. Each situation where mixing may occur may be somewhat unique and specifics of the agreement need to be tailored to the circumstances. Additionally, each region is responsible for having local FWP contacts made available to land managing agencies and sheep and goat producers to resolve commingling issues should they occur.

During the later stages of producing this conservation strategy the United States Animal Health Association (USAHA) through a broad-based working group they established in 2007, which included members of the American Sheep Industry, produced a report "Recommendations on best management practices for domestic sheep grazing on public land ranges shared with bighorn sheep". The recommendations contained in that report are similar to and

complimentary to those contained in this Health Monitoring and Management section.

This statewide protocol is designed to give guidance to field personnel in handling situations where bighorn sheep come into contact with domestic sheep.

There are a couple of scenarios regarding commingling that warrant different responses.

Situation 1

Because a quick response to a situation where commingling occurs is critical, FWP personnel will respond immediately when the person(s) reporting confirmed or suspected contact is available to further assist or when sufficient information has been obtained for an immediate field response. The following actions will occur:

- 1) Field personnel need to respond as quickly as possible to reports of bighorns commingling with domestic sheep and goats.
- 2) When it is confirmed that bighorns have made contact with domestics, the bighorn(s) must be lethally removed and promptly sent to the Wildlife Laboratory in Bozeman or a field necropsy performed by a trained biologist. When feasible, the lab should be contacted prior to removing the animal. This will allow the lab to prepare for necropsy and analysis of the carcass soon after it arrives. If the carcass is being transported to the lab, it should be done immediately (as soon as the animal is killed). As a last resort the carcass can be frozen. Information that should accompany a removed animal includes the name of the person who made the removal, the time and place of the removal, an explanation of the reason for the action, and a description of symptoms, if any, of the euthanized sheep.
- 3) If contact with domestics is not certain (e.g., a bighorn was observed in the area but may not have made contact), some discretion can be allowed in the field as to what action to take. However, if there is reasonable suspicion that contact likely occurred, the animal should be immediately dispatched.
- 4) If bighorns are using pastures common to domestic sheep and goats, every effort should be made to discourage animals from commingling. This is especially true in situations where bighorns are just beginning to move onto cultivated lands where contact with domestics could occur over time.

- 5) There may be situations where extenuating circumstances may dictate different action from that listed above. In these situations, there needs to be agreement between field staff and regional managers as to the action taken.

Situation 2

In situations where communication via cell phone or other timely communication is not possible, such as in remote country with no phone coverage, a previously signed agreement with the producer, as mentioned earlier will facilitate the following actions.

- 1) Any bighorn sheep contacting domestic sheep may be lethally removed by the producer or their herders on their federal and/or state-managed allotments or on private and leased land.
- 2) Bighorns close to domestic sheep within the same lands/situations as above, where potential for contact is imminent, may be lethally removed by the producer or their herders.
- 3) When bighorns are greater than half a mile from domestic sheep and goats on these same lands/situations, producers or their herders will make every effort to contact FWP personnel, haze the bighorns, or move domestic animals to address the situation before lethally removing bighorn sheep.
- 4) Producers or their herders will inform FWP within 24 hours of lethally removing a bighorn sheep or as soon as practical thereafter, considering access and logistic limitations.
- 5) The carcass of any bighorn sheep lethally removed as described above will be field dressed and preserved in as practical a manner as circumstances allow, to prevent spoilage. In Situation 2 as described, field dressing is recommended to make future handling easier as it may not be possible to retrieve the carcass for a few days. Testing for disease pathogens under these circumstances and time periods is not feasible.
- 6) The carcass, including the head and horns, will be left intact for collection by FWP.
- 7) The person killing a bighorn is required to take an FWP representative to the location of the kill.

In all situations where commingling has occurred and bighorn sheep have been lethally

removed, FWP and/or the producer or their herder will continue to monitor the area to determine if there are more bighorn sheep. Likewise, if contact has not occurred but sheep are in the vicinity (within half a mile) of domestic sheep and goats, bighorn sheep distribution will be closely monitored and bighorns may be hazed from the area. When possible, domestic animals will be removed from the vicinity to prevent contact from occurring.

Montana Fish, Wildlife & Parks Recommendations Regarding the Use of Domestic Sheep and Goats for Noxious Weed Control in the Vicinity of Bighorn Sheep

Over the course of the past decade, the use of grazing domestic animals, specifically sheep and goats, has increasingly become a method utilized for controlling noxious weed infestations. The increased use of domestic animals for noxious weed control has been accompanied by much information targeted at producers and interested parties on using this technique. Publications on how to best apply domestic grazing are abundant and informative for those who want to learn more about the details of this weed control method. The common term for this technique has become “targeted grazing.” While there is much information available on how to apply targeted grazing, there is little documentation or mention of the potential negative impacts on selected wildlife species.

FWP has long recognized that proper grazing by certain classes of livestock can be beneficial to the vegetation resource and compatible with wildlife management goals and objectives. FWP also fully recognizes the impact that noxious weeds can have on Montana’s range resource; hundreds of thousands of sportsperson license dollars are spent annually in the effort to control noxious weeds on lands that FWP owns or administers. However, not all classes of livestock, in this case domestic sheep and goats, are compatible with all species of wildlife. In this situation, domestic sheep or goats in close proximity to bighorn sheep can result in disease transmission to wild sheep with sometimes catastrophic declines in affected wild sheep populations (Buechner 1960; Martin et al. 1996).

The report produced by the WAFWA/WSWG “Recommendations for Domestic Sheep and Goat Management in Wild Sheep Habitat” is the basis for FWP’s recommendations dealing with the use of domestic sheep and goats for noxious weed control in the vicinity of existing

bighorn sheep populations. It is the intent of FWP, through these recommendations, to protect the health of Montana's bighorn sheep by maintaining effective separation of bighorn sheep and domestic sheep and goats that are being used for noxious weed control. FWP realizes that there is a desire by private and public land managers to use domestic sheep and goats for noxious weed control and that at times this can be an effective control method. But because of the high potential for disease transmission when commingling occurs between wild sheep and domestic sheep and goats, it is the intent of FWP to coordinate with local county weed districts or other appropriate agencies/organizations involved with weed management to preclude the use of domestic sheep and goats for noxious weed control in areas where contact between wild sheep and domestics is likely to occur.

FWP's primary tool for helping to determine where contact may occur is the mapped distribution of the 45 bighorn sheep populations in Montana. These maps were updated by FWP biologists in 2008 and will be updated again in two years. Maps depict the primary distribution of a majority of the bighorns in a particular population, but some bighorn sheep, particularly young males, are known for moving outside this mapped distribution.

When identifying the risk of contact between domestic sheep and goats and bighorn sheep, it is important to note that while spatial overlap of bighorn sheep and domestic sheep may occur, temporal overlap may not. An example of this would be where domestic animals are used for noxious weed control on bighorn sheep winter range during the period when bighorns have migrated to higher elevation summer range. In such a situation, it may be appropriate to use domestics for weed control. However, it takes professional local knowledge of bighorn sheep distribution, as not all bighorns in a population may be seasonally migratory. It is common for some portions of bighorn populations to be sedentary and remain on winter range areas year-round. This is especially prevalent with transplanted populations. Additionally, some populations, such as bighorns in the Missouri River Breaks in central Montana, don't have well-defined seasonal ranges and their year-round distribution overlaps. Therefore, the knowledge of bighorn sheep distribution by the local FWP biologist as well as others is a necessary component for determining where it may be appropriate to use domestic animals for noxious weed control. Further, information regarding the potential for parasite transmission is needed when evaluating the effects of temporal overlap of range utilized by bighorn sheep and domestic sheep and goats. Parasite

transmission can occur between bighorn sheep and domestic sheep and goats even though the species use range at different times of the year.

The ultimate objective is to maintain effective separation between wild sheep and domestic sheep and goats. When contact does occur, wild sheep must be physically and usually fatally removed to prevent disease transmission to other wild sheep. Because this situation is preventable by the use of other methods of noxious weed control, other methods are the preferable choice when effective separation cannot be reasonably guaranteed.

FWP realizes there may be some risk of interaction between wild sheep and domestic sheep and goats under the best of circumstances. To provide direction to all parties involved when interaction occurs, a statewide protocol has been developed as part of FWP's Conservation Strategy for bighorn sheep and will be referenced where appropriate in this strategy.

The following recommendations have applicability to state wildlife agencies, federal land management agencies, wild sheep conservation organizations, domestic sheep and goat producers/permittees, and private landowners. While many of the recommendations contained in the WAFWA report are broader in scope than the noxious weed issue, the ones pertaining primarily to the targeted grazing concept were used in developing FWP's recommendations regarding that issue. Most of the following recommendations pertain more to land management agencies; however, many are pertinent to all parties involved.

In order to maintain effective separation between bighorn sheep and domestic animals used for noxious weed control, FWP commits to the following actions and makes the following recommendations:

- 1) Regional FWP personnel will coordinate with county weed districts or other appropriate agencies/organizations involved with weed management to preclude the use of domestic sheep and goats for noxious weed control in areas where contact between wild sheep and domestic sheep and goats is likely to occur. FWP will provide educational information and offer assistance to county weed districts regarding the disease risks associated with domestic sheep and goat use. FWP, through its knowledge of bighorn sheep distribution statewide, will help define when and where the use of domestic sheep and goats for weed control is likely to result in effective separation of the different species.

- 2) FWP has developed a statewide protocol (see Statewide Protocol for Resolving Situations Where Bighorn Sheep and Domestic Sheep and Goats Commingle) to address dispersing or wandering wild sheep that may contact domestic sheep and goats and continue traveling, either back to their source herd or to other wild sheep herds, with or without infectious disease. This protocol identifies what and when specific actions are to be taken (e.g., kill and medically evaluate wandering wild sheep), and specifies who is authorized to take those actions. Furthermore, this protocol will be openly discussed with affected stakeholders, so there is clear and widespread understanding of subsequent management actions by FWP. This protocol includes notification requirements, wildlife health intervention (if appropriate), and post-contact monitoring strategies. FWP will also work with appropriate state and federal agencies and industry representatives to develop an effective, efficient, and legal response protocol for errant domestic sheep and goats (e.g., feral, abandoned), for which no owner can be determined and which threaten to come in contact with wild sheep.

Recommendations to BLM and USFS (and Other Land Management Agencies)

- 1) FWP recommends that land management agencies responsible for domestic sheep and goat grazing allotments, trailing routes, vegetation management (e.g., weed control, enhancement of conifer regeneration), or any other uses involving domestic sheep and goats should only authorize such use where mechanisms are in place to achieve effective separation from wild sheep.
- 2) FWP realizes that under the best of circumstances wandering bighorn sheep may come into contact with domestic animals. When this occurs, land management agencies should require prompt notification of interaction between wild sheep and domestic sheep and goats by permittees and their herders. Notification procedures (including phone numbers/contact information for permittees and use of satellite phones in backcountry settings) should be included in the Annual Operating Instructions for grazing allotments and trailing permits or when domestic animals are used for weed control.
- 3) Ensure advance written instructions exist (such as USFS Annual Operating Instructions) to address management, retrieval, and disposition of stray domestic sheep and goats used for noxious weed control left on public lands prior to and/or after grazing/trailing/permitted on- and off-dates.
- 4) FWP recommends to land management agencies that land use and resource management plans, where relevant, should specifically address the issue of potential domestic sheep and goat interaction with wild sheep. Land use plans should evaluate the suitability of permitting activities involving domestic sheep and goats. Plans should address this issue and identify general areas of public land where domestic sheep and goats should not be permitted for weed control, commercial grazing, recreational packing, conifer regeneration, vegetation management, and other management activities.
- 5) Where mandatory buffer zones (frequently cited as a minimum of nine airline miles [13.5 km]) between domestic sheep and goats and wild sheep are used to ensure effective separation, it should be recognized that buffer zones apply to herds or populations of wild sheep, rather than wandering individuals (most often sub-adult bighorn rams). In some cases, buffer zones have been a very effective strategy to reduce the opportunity for interaction between wild sheep and domestic sheep and goats. However, in continuous wild sheep habitat, where wild sheep movements may eventually exceed a priori expectations, buffer zones may not be the most effective or practical tool (Schommer and Woolever 2001).
- 6) FWP recommends that land management agencies, in collaboration with state livestock health agencies, work with producers/permittees to develop specific health certification protocols and require certification before domestic sheep are turned out for any vegetation management effort. The objective of these protocols is to prevent the turnout of sick or diseased domestic sheep and goats on grazing allotments, on trailing routes, or when used for weed control. Sick or diseased animals on range should be reported to land management or wildlife agency personnel as soon

as possible after recognition; upon notification, interagency coordination should promptly occur. Analogous to requirements to use certified weed-free hay on public lands, or requirements to clean logging or other heavy equipment that have been operating in areas where noxious weed seed might be inadvertently scattered into new areas, domestic sheep and goats should be healthy before being turned out. Alberta and British Columbia (<http://www.for.gov.bc.ca/hfp/publications/00006/>) have developed specific health certification protocols that are required before domestic sheep are turned out for vegetative management in conifer reforestation efforts. The higher the risk of contact between domestic sheep and goats with wild sheep, the higher the certainty of domestic animal health must be. It should also be recognized that “healthy-appearing” domestic sheep and goats might still carry pathogens that can be transmitted to wild sheep. Producers/permittees must take appropriate measures to prevent turnout of sick or diseased domestic sheep and goats on grazing allotments, on trailing routes, or in weed control situations. Sick or diseased animals should be removed or otherwise eliminated as soon as possible after their recognition.

- 7) Proportional to the risk of contact between domestic sheep and goats and wild sheep, land management agencies should work with producers/permittees, state wildlife agencies, wild sheep advocates, and others to implement a variety of mitigation strategies, such as herders, dogs or other guarding animals trained to repel animals foreign to domestic sheep bands or goat flocks (such as wandering wild sheep, various predators), confinement of domestic sheep and goats at night to minimize strays, and adequate fencing configurations designed to achieve the most effective separation possible.
- 8) Land management agencies should clearly define the process, protocols, and timelines for short-term or emergency management actions when intervention is needed to minimize or eliminate the risk of interaction between wild sheep and domestic sheep and goats.
- 9) Land management agencies should closely evaluate the timing of permitted domestic sheep and goat grazing and/or trailing activities, to reduce disease transmission

risk. For example, grazing domestic sheep when ewes are in estrus heightens the possibility of contact between wild sheep and domestic sheep. Effective separation should be based on temporal and spatial separation of wild sheep and domestic sheep and goats.

Suggested Management Practices on Private Lands

- 1) Support “effective separation” fencing standards whenever feasible, including the options of electric outrigger fences or double fencing methods to reduce transmission of respiratory disease agents. The goal of separation fencing is the physical prevention of nose-to-nose contact and an adequate physical distance to prevent aerosol transmission. Outriggers of electric wire two feet from page- (woven) wire fencing or double fencing consisting of two page-wire fences, eight feet high, with a minimum spacing of at least 10 feet, are considered effective. A combination of fencing methods may be most effective to ensure that wild sheep do not come into contact with domestic sheep and goats on private land.
- 2) Where contact between domestic and bighorn sheep may occur, work with private landowners and agencies to consider alternative weed management strategies to reduce risk of contact while adequately managing weed problems.
- 3) Any observed interaction between wild sheep and domestic sheep and goats should be promptly reported to FWP. FWP will make local contact information readily available to the producer.

Response to Bighorn Sheep Die-Off Protocol

Montana’s bighorn sheep populations are generally healthy and robust. On occasion, however, die-offs do occur. Die-offs are sometimes moderate and localized, affecting only a small portion of a population. Such events can lead, however, to an “all-age” die-off where both sexes and all ages of bighorns are subjected to disease and which occasionally results in over 90% mortality of a population. Die-offs are more common in the late fall and winter seasons, and mortality is generally due to pneumonia, which can occur after contact with

domestic sheep or goats but may occur with no known contact between these different species. Once these events begin, often there is little that can be done to effectively slow the progress of the die-off.

Montana FWP, the primary agency responsible for managing wildlife in Montana, needs to respond to die-off events on a number of fronts in a timely and efficient manner. There are two major aspects of equal importance that need to be addressed when FWP becomes aware that a die-off is occurring. First is communication, using appropriate media, depicting the details of the die-off as known at that time to other pertinent managing resource agencies, nongovernmental organizations, stakeholders, and to the public at large. Second is the biological response. An informed decision on an appropriate course of action/intervention must be made using all available biological data, including the extent and stage of the die-off, type of biological samples to be collected, connectivity to other sheep herds, species involved in the die-off, and other pertinent information as deemed necessary. Additionally, communication needs to occur between parties responsible for determining a biological response and parties addressing the media and stakeholders.

The purpose in developing this protocol is to suggest and promote a coordinated process detailing which personnel are assigned to what tasks and which agencies and groups to contact and at what stages of the die-off; deciding some aspects of the biological response; and ensuring that all these actions occur in a timely, efficient, and open manner.

Die-off events are unique and vary to some degree in the extent and stage of a die-off when reported, the method of detecting or determining that or if a die-off is in progress, and access to the area where the die-off is occurring.

The following provides one example of a logical protocol for determining response actions and personnel responsible for carrying out certain duties during a die-off. Particular situations may dictate that the regional supervisor, in conjunction with the Wildlife Division administrator, make variations in responses or personnel from those suggested here.

Actions Items and Timeframes for Responding to a Bighorn Sheep Die-Off

Once a die-off is reported, the following sequential actions should occur. The order of items may vary depending on the situation, and some items are carried out simultaneously.

1. Initial Notification of Die-Off

Once a die-off is reported, the receiving FWP party shall immediately notify the regional wildlife manager and local biologist with details regarding the event (where, when, and who reported the die-off).

2. Assess Status of Die-Off

As soon as feasible, the local biologist shall assess the extent of the die-off. Depending on the situation, the assessment can in most cases be done effectively through the use of a helicopter if occurring over a large inaccessible area such as a bighorn winter range. The biologist should document the number of sick and dead animals. Symptomatic animals are frequently observed coughing if pneumonia is involved. Results of this survey shall be communicated to the regional wildlife manager as soon as possible. The regional wildlife manager shall immediately contact the Wildlife Division administrator/Wildlife Management bureau chief with details of the die-off.

3. Determine Course of Action

The wildlife manager, in consultation with the local biologist and the wildlife veterinarian, formulates a course of action based on the initial assessment by the local biologist. The response can be quite variable depending on a number of factors, including the stage of the die-off and the scope of the die-off (the number of animals and extent of the population affected). Once a course of action is determined, that action is communicated to all parties in detail.

While there has been limited success with field treatment of bighorns during pneumonia outbreaks through application of antibiotics, treatment is often difficult to accomplish (Coggins and Matthews 1998). Administration of an adequate dosage of antibiotics to large numbers of free-ranging animals is extremely difficult and expensive. Additionally, treatment of bighorns through application of anthelmintics or vaccines after the die-off event with the objective of improving lamb survival have generally not been effective (Aune et al. 1998; Miller et al. 2000; Cassirer et al. 2001). A basic course of action in early-stage die-offs would be to remove sick and dying animals and collect biological samples for testing. This in itself may help reduce the extent of the die-off. Die-offs occurring during the rut may be particularly difficult to control, as rams traveling between ewe groups may act as a vector for the disease.

4. Initial Assessment of Possible Cause(s)

An initial assessment shall be made as soon as

possible as to the cause of the die-off. Generally, at this stage it can be difficult to determine the cause(s); however, if there are domestic sheep or goats in the vicinity, potential contact between wild sheep and domestic animals should be investigated. Caution needs to be exercised at this time in definitively stating what the cause may have been or the likely involvement of domestic livestock. However, certain items should be considered, such as the overall condition of live sheep and if the die-off is occurring during the winter shortly after the hunting season. If occurring shortly after hunting season, hunters from that particular hunting district could be contacted and asked about the general condition of harvested animals.

5. Communication Process/Contacts List

The regional wildlife manager informs the regional Information and Education Program manager of the situation, and they jointly develop the process for informing all stakeholders, including who to contact, priority in which contacts will be made, who will make contacts, and drafting a press release. Some contacts need to be made prior to the press release going out. A list of possible contacts, which may vary depending on the situation, would include state and federal agencies that have responsibilities in managing bighorn habitat in the area of the die-off. Contacts to these agencies would be made at the local level where the die-off is occurring by the regional wildlife manager or local FWP biologist. The Montana state veterinarian (Department of Livestock) should be informed of the die-off by the wildlife veterinarian. If contact with domestic sheep may have occurred, the executive director of the Montana Woolgrowers Association should be informed of the situation. Other contacts to appropriate nongovernmental organizations should be made by the regional wildlife manager at this time. Making these contacts will normally take one to two days, at which time the regional Information and Education Program manager can distribute the news release.

6. Designate Primary Contact Person

A designated contact person within the FWP Region where the die-off is occurring shall be identified so that responses to inquiries are consistent and accurate. Normally, the regional wildlife manager serves as the primary contact person providing information on the die-off to the media. Depending on the situation, the local biologist or the regional Information and Education Program manager may fill that role.

7. Biological Sampling

The wildlife veterinarian will coordinate any sampling of dead or dying bighorn sheep according to existing protocol. This includes determination of an adequate sample size of specimens needed to assess the die-off and tissue collection and submission protocols. It is recommended that tissue collection and submission protocols meet or exceed recommendations made by the Wildlife Health Committee of the Western Association of Fish and Wildlife Agencies. Additionally, if any interventions are planned, those actions need to be closely monitored to determine their effectiveness in moderating the die-off. The regional wildlife manager is responsible for assigning adequate field staff to collect necropsy samples, continuing assessment of the die-off, and, in conjunction with the wildlife veterinarian, for determining what follow-up monitoring of the die-off is appropriate by field staff. The wildlife veterinarian needs to communicate to field personnel the symptoms to look for in determining sick animals and provide field staff with training on sample collection and handling protocols.

8. Final Assessment of Extent of Die-Off

Assuming the die-off occurred on winter range, a follow-up aerial survey should be conducted by the local biologist to determine the extent of the die-off. The survey should be conducted prior to animals moving off of winter range. A die-off event may last several months so periodic observation is required to determine if bighorns are no longer dying. The local biologist will relay this information to the regional wildlife manager as soon as possible.

9. Final Assessment of Possible Cause(s) of Die-Off

Once all the biological sample results have been received, a thorough assessment by the wildlife veterinarian, wildlife lab supervisor, and other wildlife health specialists evaluating the potential cause(s) of the die-off will be conducted. The results of this analysis need to be completed in a timely manner, data and interpretation assembled in report format, and the report sent to the regional wildlife manager and the Wildlife Division administrator. However, laboratory results may not be received for several weeks after submission, delaying completion of a final report.

10. Final Communication/News Release

A final communication/news release detailing the extent of the die-off and potential cause(s) should be put together with the parties to be

contacted and those responsible for making the contacts being the same as in item (5) above. This could include whom to contact if skulls/carcasses are found, what information is useful for staff to collect these remains, and the regulations for possessing ram skulls.

11. Future of Bighorn Sheep Population

Once the details of a particular die-off are known, a detailed write-up needs to be done by the local biologist that includes input from the specialist(s) involved in the event and depicts all known details of the die-off. Copies of this report will go to the FWP Region, Helena Wildlife Division, and the wildlife lab. Each die-off event can be somewhat unique. Sometimes die-offs occur rapidly with wild sheep dying within a few days, while other times a die-off may last a couple of months with the animals' condition deteriorating slowly before death. Periodic monitoring of remaining sheep needs to occur. If new lambs are born the following spring, it is likely that lamb survival will be compromised, and this should be documented if possible from the ground. If augmentation of the population may be considered in the future to promote recovery of the population, the cause(s) of the die-off need to be determined and rectified if at all possible prior to any release of bighorn sheep (see Translocation Program section).

Genetics

There are four main reasons why genetics should be considered in the management of bighorn sheep. First, molecular genetic markers can identify populations experiencing a loss of genetic variation and inbreeding, which may be due to reduced connectivity and small population size (Hogg et al. 2006). Second, genetic data can also help detect potential undesirable effects of selective harvest on important attributes such as horn and body size (Coltman et al. 2003; Allendorf et al. 2008). Third, genetic tools can aid forensics by detecting poaching and illegal sale of body parts such as trophy skulls or horns (Manel et al. 2002). Finally, genetic markers can be used to identify the presence of and track the transmission of pathogens or parasites within and among individuals and populations (Archie et al. 2008). Much of the above information can be obtained using polymerase chain reaction (PCR)-based technologies allowing for noninvasive sampling of feces, hair, urine, or saliva (Taberlet et al. 1999; Luikart et al. 2008b; Beja-Pereira et al. 2009).

Loss of Genetic Variation And Inbreeding

Isolated populations with small size will experience rapid loss of genetic variation and inbreeding (mating between relatives). The rate of loss of genetic variation (heterozygosity) is determined by the effective population size (N_e), not the population census size (i.e., abundance). The rate of loss of variation and N_e can be estimated by analyzing approximately 10 to 20 molecular genetic markers (e.g., microsatellites) and DNA samples from approximately 30 to 50 individuals from the population of interest.

In wild populations N_e is almost invariably less than the population census size (N_c). The N_e is reduced below the N_c by phenomena such as skewed sex ratio, variation in reproductive success among individuals, and changes in population size through time. Most estimates of N_e suggest that it is only about 10-50% of N_c (Frankham 1995). Given a breeding structure where few males dominate reproduction, the N_e/N_c ratio of bighorn sheep is probably at the lower end of this range. For populations with 50 to 200 adults, therefore, N_e may be only 10 to 20, resulting in a rapid loss of genetic variation and an accumulation of inbreeding.

Many of Montana's 45 bighorn sheep populations are relatively small, isolated, and were founded with few individuals. Because of small founding size and low abundance, many are likely to have low N_e , making them susceptible to the random loss of genetic variation, inbreeding, and the random increase in the frequency of harmful genetic variation (deleterious alleles). Loss of genetic variation, especially particular variants (alleles) is also expected to result in reduced adaptability and may also increase the susceptibility of the animals to particular parasites and diseases. Furthermore, because of their small size and isolation over time, the amount of inbreeding in many populations will increase and eventually result in inbreeding depression, which is defined as the loss of fitness in inbred individuals. All of these factors act concurrently to increase the risk of extinction (Berger 1990), and many have been observed in bighorn sheep populations (Hogg et al. 2006; Luikart et al. 2008a).

Loss of genetic variation and inbreeding in populations can be ameliorated by transferring individuals among populations, a process commonly referred to as genetic rescue (Westemeier et al. 1998; Madsen 1999; Vila et al. 2002; Tallmon et al. 2004; Hogg et al. 2006; Pimm et al. 2006; Fredrickson et al. 2007). Thus, any bighorn sheep population that has been small (e.g., less than 50 to 100 breeding adults) and isolated for more than two to three

generations (approximately 10 to 15 years) could be considered as a candidate for genetic rescue.

Translocations, however, are not without risk and should be conducted only when data suggest the need, and should carefully consider the potential risks of disease transmission. In the absence of demographic data directly indicating inbreeding, the need for genetic rescue can be assessed indirectly by using molecular genetic data obtained from PCR-based genotyping technologies (e.g., microsatellite genotyping). Such data can be used to estimate degree of genetic isolation among populations, levels of genetic variation within populations, levels of inbreeding or degree of relationship among individuals within populations, and N_e , and also look for signatures of recent population declines (bottlenecks) such as absence of rare alleles (Luikart and Cornuet 1998).

Genetic markers can help identify source populations with the highest genetic diversity for use in translocations. They can also help identify source populations that are genetically distinct and therefore useful for maximizing variation in populations by mixing individuals from different populations (e.g., Maudet et al. 2002). Molecular genetic studies can help address the following important types of questions: Are the native populations from northwest Montana genetically distinct from the Sun River population and thus represent a special genetic resource for translocations? Does the Sun River population have many alleles at disease-related genes that were lost during translocations to found new populations, such as Wildhorse Island? Does the Wildhorse Island population have low genetic variation and thus is not always the best source for augmenting genetic diversity through translocations?

Molecular genetic markers can help estimate rates of gene flow and movement between populations and thus can help to monitor connectivity. Connectivity is important for assessing extinction risk due to isolation (e.g., demographic and genetic stochasticity) but also for assessing risk of disease spread between populations. Genetic markers are now being used directly on parasites to assess parasite spread and disease transmission between populations (Archie et al. 2008). For example, genetic markers for *Pasteurella* bacteria, viruses, or lungworms might be useful to track parasite transmission among bighorn populations.

Selection on Phenotype

Harvest of wild populations can cause unintended (“unnatural”) selection (Allendorf et al. 2008). For example, harvest of only large-horned rams led to reduced horn sizes in an isolated bighorn population from

Alberta, Canada (Coltman et al. 2003). If this population were not isolated, it is possible that horn size would not have been reduced and gene flow would prevent loss of genes (alleles) for large horn size. Horn size and other traits (body size) are likely heritable (i.e., have genes underlying the trait). Thus harvest could selectively remove genes (alleles) associated with traits desired by and removed by hunters, such as large horns. Genetic studies combined with studies of phenotype (e.g., horn size) can detect unintentional selection and phenotypic change caused by harvest in wild populations. Managers could collect long-term data on horn size as well as DNA samples (from horn plug drill shavings or skin/muscle tissue) to initiate a long-term monitoring program to watch for genetics and phenotypic effects of harvest on bighorn sheep.

Forensics

Genetic markers can help detect illegal killing and trafficking of bighorn sheep and their body parts (e.g., trophy skulls or horns). Genetic markers determined by analyzing a meat sample or bloodstain can identify the species, individual, sex, and even population of origin of an individual (Manel et al. 2002). Identification of the population of origin of an individual requires having genotyped 20 to 30 individuals from the putative population of origin and ideally other potential populations of origin. FWP could collect high-quality DNA samples from bighorn populations to allow for long-term monitoring of loss of genetic variation, connectivity, and the detection of poaching.

Pathogen Prevalence and Transmission

Finally, DNA markers can help to understand the causes and consequences of parasite infection, including the emergence, spread, persistence and evolution of infectious disease (Archie et al. 2008). Parasite DNA markers can be used to track parasite spread and infer population history (Beja-Pereira et al. 2009). DNA markers are available for macroparasites (gastrointestinal worms and lung worms) and microparasites (lung viruses and bacteria such as *Pasteurella*) that infect bighorn sheep. Molecular genetic markers are becoming available for an increasing number of parasites and will allow studies of how the spread of disease is influenced by landscape features (domestic animals, livestock feed lines, farms, and rivers) and environmental variables (temperature and humidity). The combination of host and parasite genetic data in a landscape genetics (Manel et al. 2003) framework promises to lend new insight into how landscape features shape the movements of parasites.